Unclassified
MICROMODULE CRYSTAL UNITS
Semi-Annual Report No. 1

DOA Order No. 3A 99 15 001 02
Contract No. DA 36 039 SC 87363
USASRDL
Fort Monmouth, New Jersey
1 July 1961 to 31 December 1961

COMMUNICATION PRODUCTS DEPARTMENT
General Electric Company
Lynchburg, Virginia

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A program to determine a design for a micromodule crystal with reliability significantly improved over that of previous designs. A second objective is to have the design be characterized by a high order of manufacturability, resulting in high yields, reliable schedules and reasonable cost.

Report prepared by

John H. Sherman, Jr.

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## PURPOSE

Prior attempts by other companies to produce a micromodule quartz crystal unit have been based upon the radical postulate that the crystal plate be rigidly mounted upon the ceramic wafer. Rigid mounting systems have consistently caused problems of great difficulty in maintaining all of the desirable characteristics of AT-cut quartz resonators. In the micromodule units the problems are complicated by the small size of the parts, and even more seriously by the fact that the plate is mounted directly to the envelope itself. The result is that the units are initially of low yield and costly and also are susceptible to destructive damage by static forces encountered in encapsulation.

The present project is committed to the goal of a compliant mounting for the crystal element inside the dimensional allocation of the original micromodule crystal element and in using other envelopes and compliant mounting systems, has resulted in successful units even smaller than those required here, confirming that the conservative approach is still valid in these miniature devices.

It is, therefore, the purpose of this project to develop micromodule crystal units of increased manufacturability and of that high order of reliability properly required of all equipment with a battlefield mission. Success in achieving this purpose is to be measured by the performance of crystal groups at 7.0 mcs, 45.1 mcs and 70 mcs against reliability specifications under hazards of accelerated aging, vibration, shock and the static forces resulting from encapsulation as well as against the normally specified requirements of frequency, accuracy and stability.

## ABSTRACT

The work is discussed in four categories:

I. Envelope and Closure

This is the substance of subcontract with the Receiving Tube Department of the General Electric Company. Prototype structures to the point of seal have proven successful.

II. Mounting Structure

Mounting structures went through six tools and two materials before a successful spring design was completed. Every crystal mounted to date has oscillated in the mount.

III. Crystal Element Design and Fabrication

Design effort is naturally focussed on the three frequencies required by the contract. The highest and lowest frequencies have posed problems of fabrication technique. The design principle employed is geometric scaling.

IV. Test

No units have yet reached the point of test against specifications in the contract.

PUBLICATIONS: None

LECTURES: None

REPORTS:

| | |
|---|---|
| July 28, 1961 | Letter Report |
| August 31, 1961 | " " |
| September 27, 1961 | " " |
| November 2, 1961 | " " |
| December 7, 1961 | " " |
| January 5, 1962 | " " |

CONFERENCES: July 14, 1961 at Fort Monmouth

Participants: Messrs. Bernstein, Guttwein, Layden, Stanley, Wasshausen all of USASRDL and Sherman of GE, CPD

Substance of Meeting:

1) Evaluate RCA approach with no commitment to follow it unless some obvious approach to improve it significantly is conceived.

2) Criticism of the previous programs are based upon: low yield, high price, and poor ability to schedule delivery; a high rate of failure during encapsulation; an excessive rate of drift in constant temperature aging test.

3) The concensus seemed to be that there was sufficient hope for a compliant mounting that the GE approach was being subsidized. Alternate proposals by other manufacturers had had to be noted, as the crystal program results

were noticeably behind the bulk of the micromodule program.

4) The resources of the USASRDL and its personnel are to be considered a resource available to GE in the program. This point was reinforced by some direct counsel on the problems of manipulation of such small blanks.

July 21, 1961 at Receiving Tube Department
Owensboro, Kentucky

Participants: Messrs. Hickle and Childs of RTD, and Sherman of CPD

Substance of Meeting:

1) A number of metal-ceramic systems and techniques are available for producing a malleable metal path through the ceramic wall.

2) A ribbon spring as proposed should prove practical to manufacture. Music wire as a material appeared attractive.

3) Improvements to the RCA package were described, but evaluated as offering no improvement in the system, but only in its execution.

4) Solder appears to be the most promising approach to closure. Fluxing would be the principal problem. Reducing fluxes such as hydrogen, methane, and hydrazine are possibilities. No tip-off is proposed in this

system so there is no means to flush residual gases from the cavity. If evaporated solder can be applied it can be protected with an evaporated gold flash and require no fluxing.

5) The test bodies will be made without wiring indentations as a cost saving measure.

November 14, 1961 at Lynchburg, Virginia

Participants: Mr. Bernstein of USASRDL and Messrs. Adkins and Sherman of GE.

Substance of Meeting:

1) Review of technical progress.
2) Review of schedule with emphasis on the magic date of April 1, 1962 for life test to be underway.

January 22, 1962 at Lynchburg, Virginia

Participants: Messrs. Hanchett, Hauser, Farmer of RCA, Mason of USASSA, Adkins and Sherman of GE.

Substance of Meeting:

1) RCA and USASSA are interested in developing a source of micromodule crystals which can produce in small quantities with a reliable delivery schedule.
2) RCA is not prepared to waive any of the previously published specifications, including the customer's power to specify the active wiring indentations.

3) It was made clear that these are not "RCA" units or "Midland" units, but are "GE" units, based on an entirely different envelope system from either, which might prove to be at best only marginally compatible with some of the RCA specifications, and which had not yet passed the battery of tests.

4) RCA would want all the specifications satisfied and tests passed, which would move the availability date to midsummer at the earliest, but offered assistance in the performance of tests. Particularly they offered their facilities for encapsulation.

January 22 and 23, 1962 at Lynchburg, Virginia

Participants: Messrs. Bernstein and Woolley of USASRDL and Adkins and Sherman of GE

Substance of Meeting:

1) Review of technical progress.

2) Discussion of this report in process of preparation.

3) Renewed emphasis on the subject of reliability of the units. A reminder that this is a research program not directed at development of production facilities (though the existence

of a capability to produce would be a gratifying bonus) came out of the discussion of the RCA and USASSA conversations noted above.

4) The Signal Corps would like to be assured that seal systems other than solder be given an unprejudiced appraisal.

## FACTUAL DATA

### I. Envelope and Closure

a) Concept

Previous work resulting in micromodule crystal units was directed to the rigid mounting of crystal plates to the ceramic body of the envelope. In the opinion of the General Electric crystal personnel, no more difficult problem could have been undertaken than this. To all of the problems associated with ordinary rigid mountings are added the results of static forces on the envelope resulting from encapsulation which are transmitted to the plate. The effect of static forces on the behavior of AT-cut crystal plates has only recently become the object of systematic study, but that there was a significant effect has long been obvious to those engaged in the design of crystal plate mounting systems. An additional hazard of this system, apparently the source of a considerable part of the troubles experienced, is that any yielding of material to relieve the forces results in electrical failure.

The present approach is based upon the conservative concept of a compliant mounting which will support the crystal plate within a cavity in the .050" thick envelope. This can be realized if two technical problems can be solved. These are (1) the design and fabrication of a compliant mounting structure of dimensions and tolerances of the requisite fineness and (2) the ability to provide an electrical path through the ceramic envelope wall having mechanical properties such that the mounting structure can be attached thereto. The second of these problems is the subject of this section of this report.

The General Electric Company manufactures an extensive line of vacuum tubes having envelopes of ceramic formed with wide area bonds to metal parts of titanium. The techniques used in this vacuum tube work provide the art for our micromodule ceramic program. By this art we are enabled to form a ductile metallic path through the wall of the ceramic to which a mounting structure can be spot-welded. There is no intention to imply that the technique used in our program is the only one available in the ceramic art. There is reason to believe that a number of alternate techniques are available. Envelope fabrication and the determination of detailed procedures for its fabrication and closure is the subject of a subcontract with the Receiving Tube Department of the General Electric Company.

b) Envelope Design

Our system is predicated upon mounting the crystals with the minimum constraint. This requires clearance on all sides of the blank. Because the mounting is to be compliant, space is required for manipulation of the mounting. Because the mounting is of small size and precarious purchase, it may turn out to be wise to grasp the plate at more than two points. These considerations led to the planning of a square cavity with corner room for mounting structure.

The cavity is, then, 0.200 inches square, with ductile metal feed-throughs hermetically sealed into a pair of diagonally opposed corners. The other pair of corners is available for another pair if it should prove necessary. If not necessary for supports, this space will be welcome for tweezer tips for manipulating blanks.

An equitable division of the 0.050" thickness seemed to be as follows: 2 ceramic wells, each .010" thick, two air gaps nominally .010" thick minimum and a crystal plate a maximum of .010" thick. In simpler and more exactly correct terms, a cavity depth of .030 is available for mounting the crystals. A mounting means having a mount center in the middle of this height will accept a 7.0 mcs crystal of any contour with a clearance greater than .005" top or bottom. The problem of devising a mount to support the blank in the center of this 030" deep cavity (the first of the technical problems) is discussed in the next section.

Thus was evolved the envelope shape used in preliminary investigations. The wiring indentations were not built into the first tools as a cost saving matter. The overall dimensions of the unit are .250" x .250" x .050". A stepped recess 220" x 220" to a step .010" deep provides a ledge for the closure. The interior cavity is .200" x .200" x .030". (Fig. 1)

c) Envelope Fabrication Details

The ductile lead-through is nickel. Originally of .018 wire, the post is now .030 in diameter punched from .010" thick sheet. The ceramic body is of the class of the Forsterites. The nickel posts do not match the ceramic and are, therefore, simply inserted into clearance holes through the ceramic wall. To the present time a small nickel tab .100" x .100" x .002" has been sealed over the lead-through holes by the active metal sealing technique to provide a vacuum tight seal, to act as a base for attaching the lead-through, and to provide an electrical path from the lead-through to the external termination point. Systems of exactly matched materials are known, but have not been applied to this time because of the difficulty in making connection to the metals involved using soft solder and orthodox fluxes. A recent refinement of the process uses the active alloy foil to braze the nickel post to the nickel foil, as well.

From the first try to the latest seal and post structure only two revisions of structure have been found necessary. They were (1) the change of post material from wire to sheet stock, with its attendant change in diameter, and (2) the use of the active alloy to braze the nickel post to the foil.

1. Wire as a post material had to be abandoned because of two defects. The sheared ends were uneven because of the distortion of the wire in the shear. This alone

made for excessive variation in the pieces sheared. In addition the tolerance on length which could be maintained in the shear was inadequate to the precision of the requirement. Changing from wire to sheet provided a means of securing a precise height and uniform shape for the surface of the post within the cavity. The punched disc is placed "die side" toward the cavity to receive attachment of the spring. The increase in diameter from .020" to .030" was dictated by considerations of punch design.

2. The original means of attachment of the post to the foil was by spot welding to the foil after the foil had been bonded to the ceramic. This method was originally planned to avoid the hazard of a meniscus of bonding metal rising between the post and the ceramic and causing the ceramic to fail due to the mismatch between the ceramic and the (relatively) massive post. Testing the preassembly of the nickel parts together was necessitated, nevertheless, when the spot welds began to fail in significant numbers (about 25% in one batch of bodies). The "punch side" of the post is concave due to the draw of the metal in the punching process. The spot weld had to be made between this unpromising surface and the foil. The last group of bodies made had the post preassembled to the tab at the time of

bonding and the bonding material displayed an apparent preferential wetting of the nickel, brazing the metal parts and forming a perfect seal without forming a meniscus in the hole.

## II. Mounting Structure

### a) Concept

From the beginning of serious consideration within General Electric of the problem of the micromodule crystal element it has seemed necessary to obtain some way of resolving the strains of the envelope before they reach the crystal plate. While preparing a proposal in response to PR&C ELE/R-4107 a structure for resilient mount was envisioned which would require a total thickness almost twice that allocated for the crystal unit. In the intervening year it became obvious that any proposal to be considered would have to be responsive to all parts of the specification for dimension.

The present program is, then, a refinement of that idea in which the mounting structure design is reduced to its simplest possible embodiment in order to reduce it to dimensions which will allow its enclosure in the .030" deep well, supporting the crystal plate clear of contact with the ceramic walls, and itself also not contacting the ceramic at any point.

The mounting structure is a leaf spring, so formed as to provide a significant length between the point of attachment to the post and the point of support of the crystal. The crystal is supported in a shape formed across the width of the leaf. The intention of the design was to have the center of the support shape fall midway in the .030 depth of the cavity, permitting the mounting of plano convex plates in either position or of providing fully symmetrical mounting for symmetrical plates. Although the realization of the spring fails to achieve this objective, it deviates in the direction of a structure of characteristics superior to the original idea. The crystal rides above the central plane indicating plano convex crystals should be mounted flat side up. This lack of symmetry allows a longer leaf from the post to the plate, increasing the compliance of the mount.

b) Fabrication of Springs

The story of the fabrication of springs is from one point of view a recounting of a comedy of errors of the sort which always has a happy ending. At least this tale does not disturb the tradition.

A spring was designed on the basis of the characteristics of the spring material most widely used in the crystal industry, music wire. This spring was to be made of ribbon .002" thick and of width which could be specified for the total strength required. The total developed length was to be .070" reduced by half the width of the leaf. It was to have the profile of Fig. 2a. Of course, no manufacturer of music wire supplied it in ribbon form.

The ribbon was finally made for us by H. Cross Co. (3229 Bergenline Ave., Union City, N. J.). This concern produces tungsten and molybdenum in foil form, rolling it from rod and took the assignment of rolling .006" and .008" round music wire into .002" ribbon completely in stride. The result was excellent ribbon of less than 1% camber in .015" and .0235" widths.

A tool was made to form the wire and it was discovered, much to our dismay, that though the spring when fabricated was within the elastic limits of the steel, the process of forming the spring took it beyond its yield point on the outside of sharp bends. Music wire is made by cold-rolling a high carbon steel. This process produces a highly oriented material of laminated structure somewhat similar to the grain of wood. When bent too sharply the material simply feathered on the outside of the bend much as a piece of green wood splits and feathers when over stressed.

Since the profile of the resulting pieces except for the feathering was exactly as desired, a heat treatment for the steel was sought which would permit the springs to be formed. (It is a metallurgical truism that annealing leaves the elastic moduli unaffected. It simply changes the plastic yield point.) For this purpose we passed sections of the ribbon through the tunnel oven at a variety of temperatures starting at a peak profile of 250°C and going to 450°C in 50°C steps. At all temperatures the feathering was suppressed, but at the cost of a clean break at the bends. (This was in an oxidizing atmosphere, the same as is required for firing standard glass-silver frits.) In despair the oven was returned to its standard temperature of 550°C. For some reason not easy to explain, we passed one more specimen through the oven at this temperature. What emerged was badly scaled with a crusty envelope of (probably) iron oxides. These were readily scraped away by the finger-nails and no loss of material could be detected by a micro-meter caliper calibrated to .0001". The surface of the ribbon had a good bright appearance, though a brown color. From this the tool turned out perfect shaped springs with no evidence of failure at the sharp bends.

We proceeded to mount some units and another error came to light. We proceeded, but we succeeded not at all, for, though beautiful spot welds were formed, every spring broke out when deflected to accept the crystal element. What happened was that every spot weld, being the site of localized fusion, was encased in a precipitation hardened shell which was the site of fracture when the spring was deflected. This explained the omission previously noted but not previously understood of high-carbon steel in spot-welding handbook charts. Low carbon steel was included.

Another material was needed for springs, one which did not harden by a precipitation process. This seemed to imply either a cuprous alloy (not beryllium copper) or a stainless steel, among the standard spring materials. Since cuprous materials are as a class more difficult to spot weld than other common metals, the new material was sought among the stainless steels.

Naturally we intended to have wire rolled again, but could find no stainless spring materials available in round wire in the .005" to .008" range. This is still not understood, for it seems beyond imagination that no suitable alloy in this range is used, for instance, in the tube industry as a grid wire. Be that as it may, our attention was directed by G. T. Winfrey to hairspring materials as used in the watch industry.

The Elgin Watch Company (Elgin, Ill.) readily accepted an order for their proprietary spring material "Elgiloy" in .002" thickness by .023" width made by slitting. This width is apparently the narrowest width to which their slitter can be adjusted, at least in our range of .015 to .025 which had come to "feel right" to us as a width. The material itself seems by its properties to be very similar to 304 stainless, being work hardened for its spring properties, slightly magnetic when in the work hardened state, but capable of being rendered non-magnetic by extended moderate temperature annealing with a concurrent improvement in its elastic properties.

Having a lower yield point, and generally greater ductility than the carbon steel the stainless was over-formed in the bending sections of the tool and drawn rather than sheared cleanly. In spot welding the spring material was thinned at the weld. The net result was a spring entirely too long, which had to be deflected farther than the originally designed deflection, and made of a material with sufficiently low yield point that the necessary deflection was an over deflection resulting in a permanent set adjacent to the weld and no mounting pressure against the plate. One test plate successfully mounted stood completely outside the cavity where it would contact the cover if the cover were to be put in place.

This precipitated a sequence of tools of small variation from tool to tool attempting to modify the dimensions, angle of bends, etc. to produce a manufacturable spring which will support the plate at the required plane in the cavity. After tool #5 still produced unsatisfactory results a moratorium was declared while a fresh look was had at the whole problem.

At this point three sketches were made of potential spring profiles based on experience to date with the material. They were 1) the "ideal" profile if no technical problems existed in the tool area (Fig. 2b), 2) the simplest spring which could conceivably satisfy the need (Fig. 2c), and 3) the spring which would be made as the nearest approximation to 1) which was feasible in the light of the difficulty inherent in tooling for this small complex shape (Fig. 2d). The springs, after all, are only .002" x .023" x a developed length in the various versions ranging from .056" to .068". The original profile had a 90° bend of radius .0015" and another of .005"; the most complex called for 3 straight sections and a circular arc, the arc joining the adjacent sides with bends of .001" radius and with no 90° bends; the one decided upon to be made was to have 3 straight sections, one right angle and a circular arc (Fig. 2d).

It goes without saying that the pieces which came off the tool bore only a token similarity to the planned shape. The "vertical" section was too long and the 90° bend was overformed. The free end beyond the circular arc, which was to aid in guiding the plate into the notch (arc) and provide a means for deflection of the spring by instrument, was lying roughly parallel to the vertical section. Not until we had some of these pieces in hand did we realize how far our "ideal" profile missed the mark. A group of these parts is photographed in Figure 3. The parts are formed in one operation and sheared in another so the horizontal sections length can be made as needed.

The three envelopes containing springs in the photograph, Figure 4, have had crystals inserted and removed several times without detectable change in the spring's properties.

This, then, finally, is our spring. It is installed by spot welding to the post with a 2.5 watt second discharge and 1 pound force. It has received, to date, only plates in the 7 mcs range. All plates have had metallized edges and none were bonded to the springs. Every plate yet mounted, even some with severe marks and blemishes in the plating has oscillated.

## III. Crystal Element Design and Fabrication

### a) Concept

The principle of geometric scaling which is the theoretical basis for our element design states that the product of any selected dimension of a resonator by the resonant frequency of the resonator is a constant for all resonators which are geometrically similar. A corollary of this is that the impedances of all similar resonators are equal, the reactance curves plotted against normalized frequency will coincide. The significant failures of the scaling principle are practical ones, that the surface finish of the quartz element and the electrode thickness cannot be scaled from substantial crystal plates to tiny ones.

Nevertheless, the principle has been our guide in designing and fabricating plates and has functioned as a reliable guide.

### b) Design Details

A diameter specification was set at .185" +.000", -.001" from consideration of standard sizes of tools. This has allowed end mills to be made from 3/16" drills in order to make plating masks and other fixtures. This allows a nominal clearance of .0075" between the edge of the plate and the side of the cavity.

At 7.0 mcs the crystal plate has a diameter-thickness ratio of approximately 19. This brings it into the range of crystals in the HC-6/U holder of about 2 mcs frequency, so a scaling from standard design data for plano-convex plates as published by Union Thermoelectric should be possible.

Entering the slide rule this scaling is done as follows:

1) Put the low frequency diameter on the C scale opposite the high frequency on the D scale.

2) Opposite the high frequency diameter on the C scale read the low frequency on the D scale.

3) Repeat for various practical diameters and calculate the scaled frequency.

4) These may be tabulated as a guide or plotted for comparison with blank designs given on pages 71 through 74 of the Union Thermoelectric Handbook. What is sought is a combination of frequency and blank diameter in the calculated table or curve which match a pair in the Handbook.

5) Calculate the contour in diopters on the high frequency blank by multiplying the contour on the low frequency blank by ratio of the frequencies.

Following this procedure the following table is constructed for 7.0 mcs and .185" diameter.

| $D_1$ | $F_1$ | $Diopt_1$ | $7/F_1$ | $Diopt_2$ |
|---|---|---|---|---|
| .600 | 2.16 | | 3.24 | |
| .575 | 2.25 | | 3.11 | |
| .550 | 2.36 | 5.00 | 2.97 | 14.8 |
| .525 | 2.47 | | 2.84 | |
| .500 | 2.59 | | 2.70 | |

Comparison with designs in production in our own shop indicated a curvature somewhat less than this should be equally satisfactory. Our stock of tools contains 13.87 diopters which we are using with promising results.

At 45.1 mcs, the blank thickness is .0044" and the diameter/thickness ratio is 42. It may be desirable to break the edge of the blank in a diopter cup, but contour is surely unnecessary.

At 70.0 mcs, third overtone, the blank is .0027" thick and the diameter-thickness ratio is over 60. No contour is necessary. Even with fifth overtone the diameter-thickness ratio is 39 and contour is not required.

c) Tools

Special tools had to be built for handling and processing this size blanks. Aside from the spindle for turning the blanks and the plating mask other tools required are a contouring machine and a fixture for holding the plates during cleaning and etching.

The plating mask (Fig. 5 ) is like any other base plating mask except for size. Our mask is 3½" x 4" and incorporates nests for 40 crystals. The mask is made to allow some flexibility in the plating, so consists of groups of ten each of four aperture sizes, .150", .120", .100", and .090".

The contouring fixture is an orthodox tripod with button holders. This fixture was considerably simplified in construction by the use of 1/8" bearing balls which are cemented onto the buttons with epoxy cement. The tripod also pivots on a bearing ball cemented with epoxy onto the end of the pivot shaft. Plates have been held into the buttons by grease, by wax, and by a cement of beeswax and rosin. Our experience has been that the hard cement does buy a certain amount of security in the handling of units in the contouring machine, as the lapping lubricant (Reprol, a product of Atlantic Refining Co.) dissolves most greases and waxes often causing crystals to fall out of the buttons. A rack to support the buttons above the hot plate while the crystals are being cemented into the buttons has been a most valuable fixture as it inhibits the overheating of the wax, etc. See the photograph Fig. 7.

Contouring is done on polished blanks in order to make it easier to follow the process. When the contour is complete the polished surface is just all gone. Contouring has been done in 5 micron $Al_2O_3$ abrasive so far, but a sample of 3 micron Microgrit (Geoscience Instruments Corp., 110 Beekman St., New York 38, N. Y.) has been procured to attempt a finer surface finish. Our polish is generated in a pin lap with cerium oxide on a pellon surface. Currently the buttons are of hardened steel. Earlier buttons made of brass just didn't have the strength at the fine rim. These parts are shown in the photographs Figures 6 and 7.

All cleaning after an initial trichlorethylene degrease is done by ultrasonic energy with detergent and water. The crystals are loaded into the stainless steel fixture on the left in the photograph Fig. 7 with the cover laid over them to prevent their floating out. Cleaning and etching is done with the crystals in the "basket" and they are removed only when the complete clean-etch-clean cycle is finished and they are ready for electroding.

We have a problem of technique in generating a polish on the .0027" thick crystals. We had not even considered not polishing them until this was suggested as possible by Mr. Bernstein. Polish on the lowest frequency crystals has been a convenience for the measurement means it provides. We have attempted to do everything possible on over-diameter blanks and round them down to size at the latest possible stage. This is normally considered desirable. Tooling for .250 diameter, and a stretcher for thin mylar carriers has just been completed. (Photo. Fig. 8) Sub-micron size abrasives have been procured to allow lapping to extremely fine surface finish without the glazing polish put on by cerium oxide.

We have had great difficulty in rounding blanks of this small size and our solution to the problem may be of some interest. The blanks are cleaned free of any abrasive (but not necessarily of water spots) and mounted dry between the spindles of the rounding machine. The whole assembly is then warmed by alcohol lamp until glycol phthalate (J. H. Young Co., 110 St. Joseph St., Pittsburgh 10, Penna.) will melt freely in contact with the stack.

The assembly is kept warmed until the glycol phthalate has run between all the crystals and also between the crystals and the spindles. After cooling the whole assembly turns as a solid piece. No fixture we have devised has given sufficiently parallel units in the stack or parallel surfaces at the ends of the stack to allow chucking a stack of .0027" plates without smashing them. Any softer cement will not hold a stack together at a diameter of .185 while turning.

d) Metallizing

We decided early that it would be advisable to metallize the edge of the plate. Unlike the standard spring holder the spring in this system barely contacts the plate, and would make a normally unsatisfactory contact with the plating. If a cement were to be used, one side of the plating would be inaccessible. It appeared at first, and it is not yet beyond prospect that the crystals would be soldered in rather than cemented. If so the solder would certainly scavenge the electrode and leave an open circuit.

For this complex of reasons, metallize the edge.

We have tried Hanovia 150 and 122A and Hanovia liquid bright platinum. All are to be fired at the highest possible temperature in the tunnel oven - we seem to have hit 570 without passing over it, and consider the platinum at this firing temperature to be apparently adequate. It is by far the easiest to apply using the cork from the bottle as the applicator, and causes no subsequent problems in the plating mask as the deposit is so thin. It must be pre-dried before firing to extract the solvent from the organic platinate solution. Contact and conductivity seem adequate even without cement. The silver pastes dried too rapidly (though a slow-drying solvent must be a possibility) left a thick enough deposit to impede insertion in the mask and were more difficult to restrict to the edge of the plate. The paste was generally harder to apply and control than the liquid.

## IV. Test

To date all pieces have been sample pieces. Stringent test requirements have been written into the contract. We take no exception to any test specification but have measured nothing against any of the specifications.

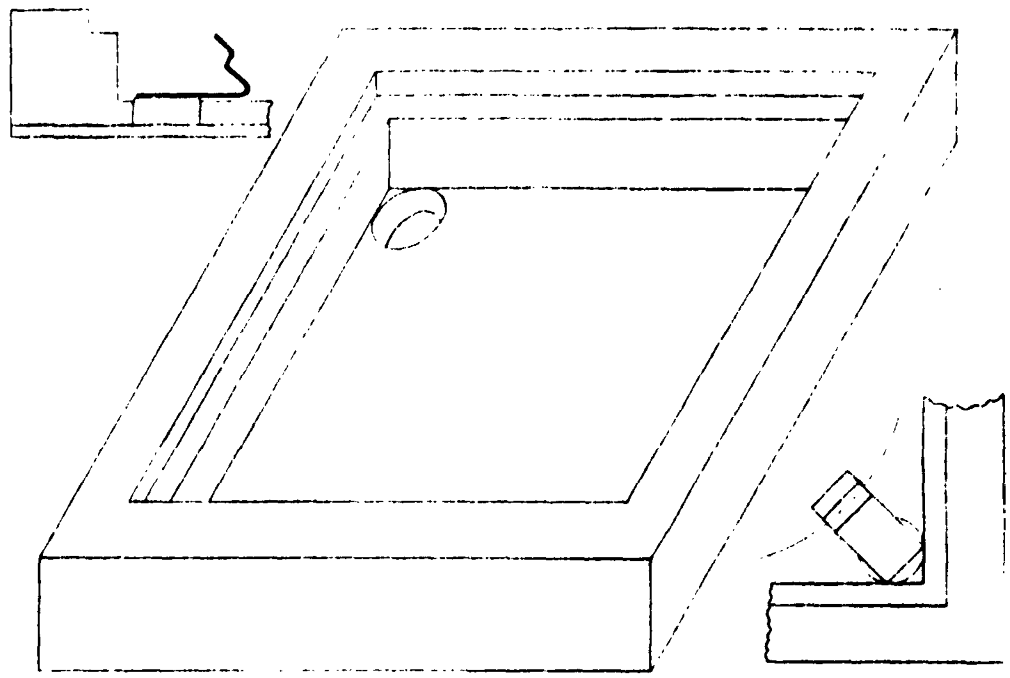

Fig. 1 Prototype Micromodule Crystal Envelope with Mounting Detail

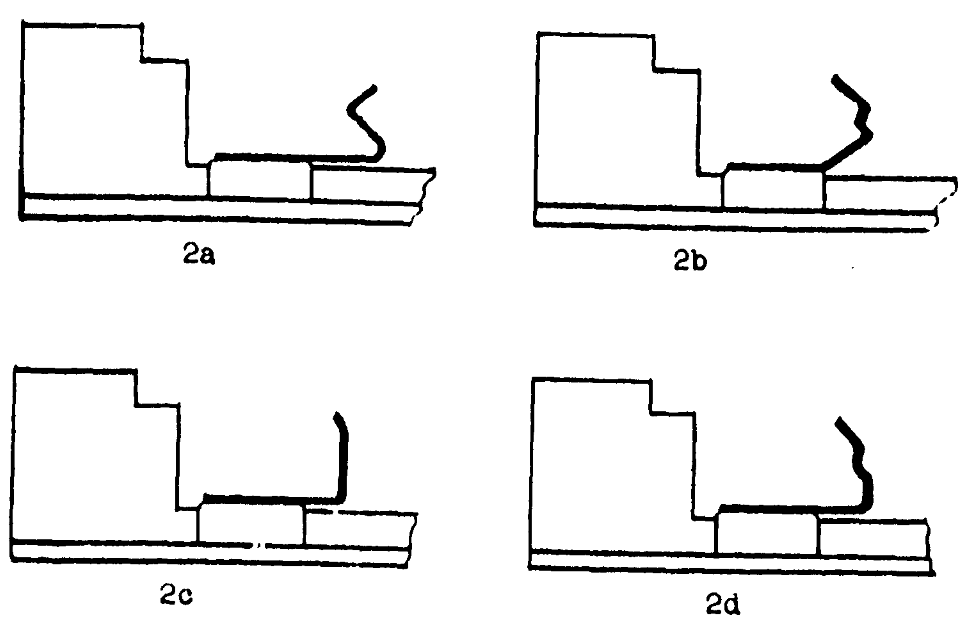

Fig. 2 Preliminary Profiles for Mounting Springs

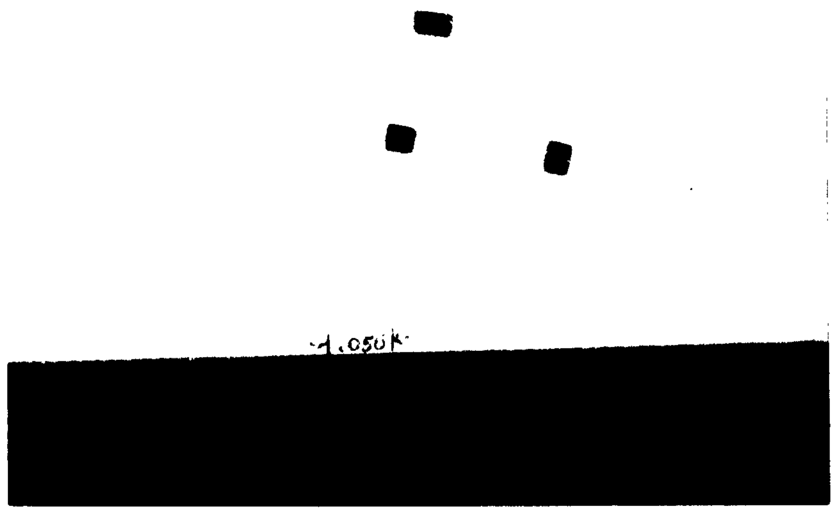

Figure 3

Mounting Springs (Final Form)

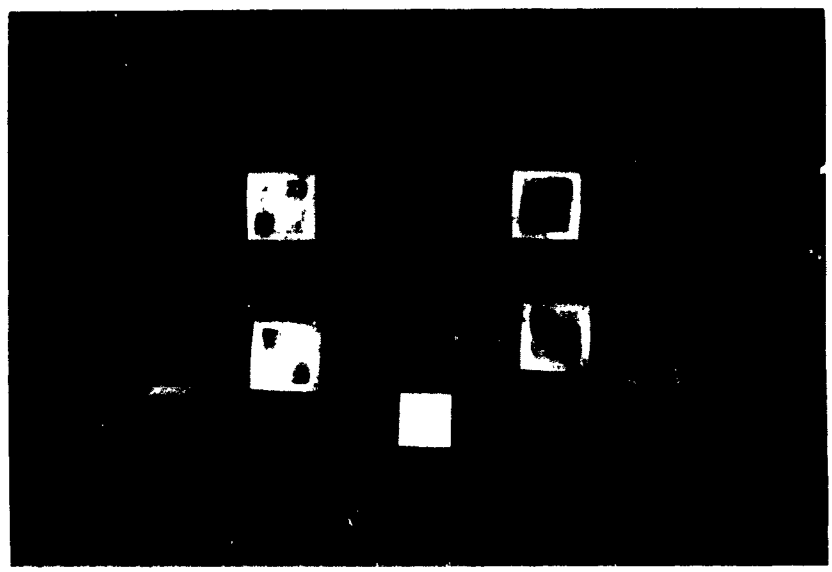

Figure 4

Engineering Prototype Components
and Assemblies

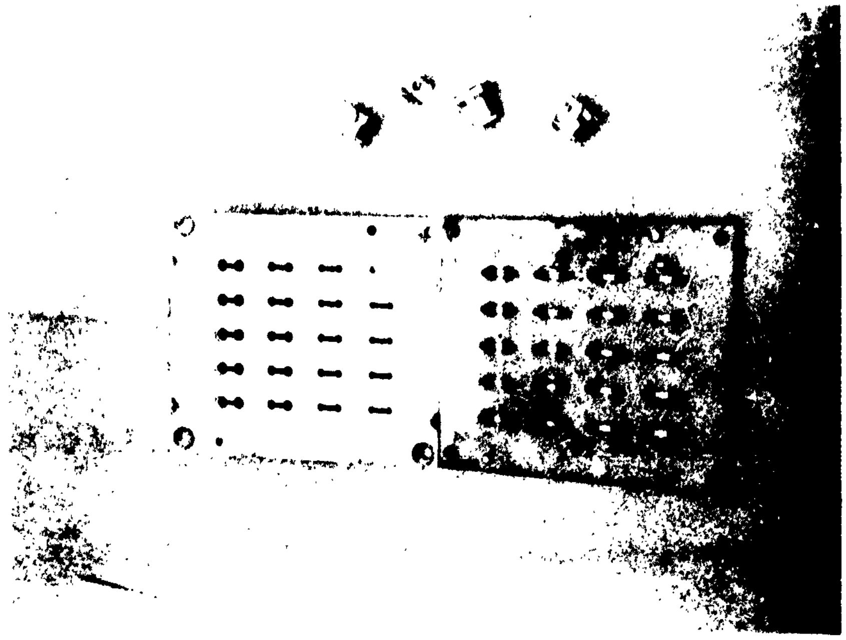

Figure 5

Base Plating Shadow Mask

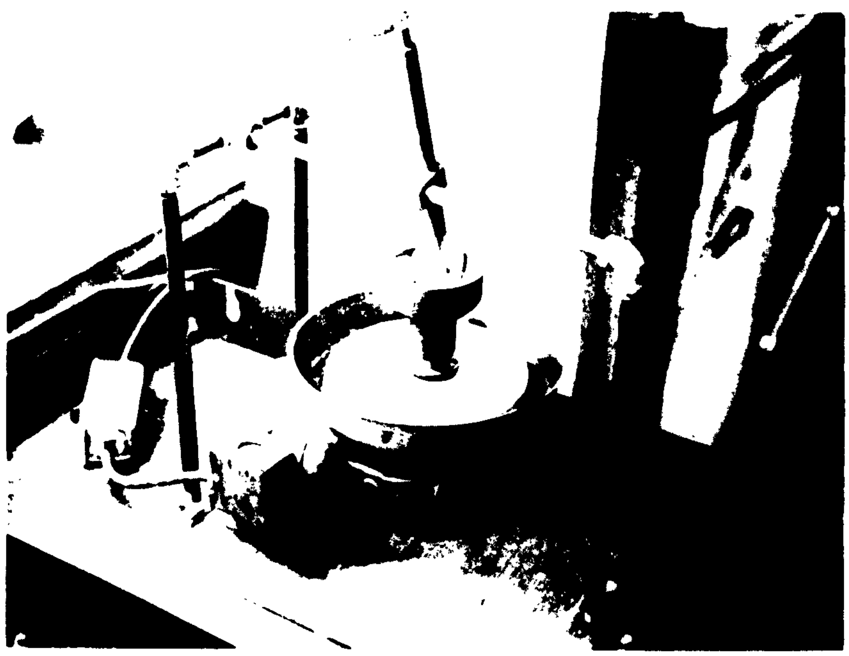

Figure 6

Contouring Machine

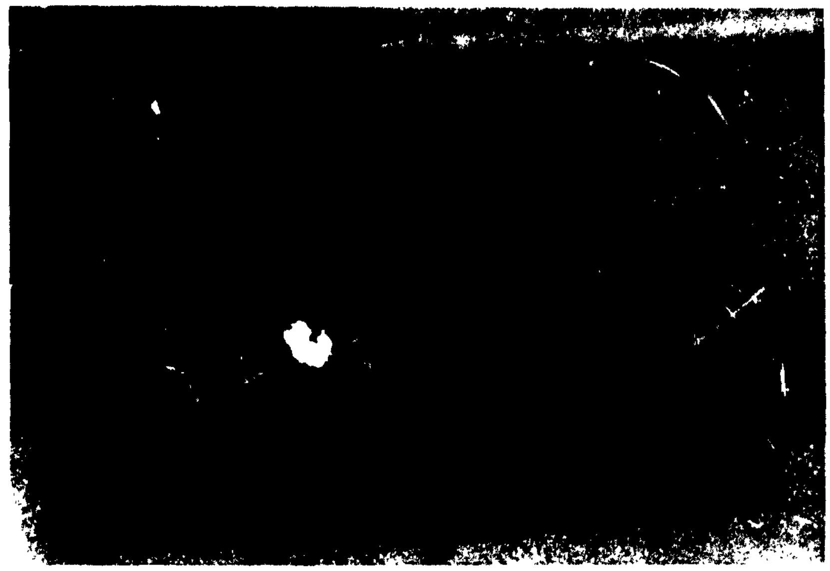

Figure 7

Special Fixtures for Processing
Micromodule Crystal Plates

Figure 8

Pin Lap with Stretched Mylar Work
Carrier and Positioning Fixture

# CONCLUSIONS

The work to this point has demonstrated the feasibility of this mounting and envelope system. Severe problems remain to be solved including some which have not as yet been tackled. Nevertheless, it is not presumptuous at this point to assert that the program will be completed on schedule with full success in meeting its objectives.

## PROGRAM FOR NEXT INTERVAL

From the standpoint that this report comes midway in the program and the next report is to be the final report, the program for the next interval is simply "Complete the Contract". This oversimplification would tend to hide the detail of what is now clear about the problems to be encountered in the next interval. For that reason the problems are now outlined in the same categories as used earlier.

I. Envelope and Closure

A set of tools is already in process to make a full micromodule wafer complete with the indentations. We will attempt to satisfy the RCA specifications for metallizing at the notches, but must at this juncture reserve judgment on the compatibility of our seal with their specification in detail. In any event connection will be assured with soft solder without the need for any special soldering techniques, either to the edge of the nickel foil or to a fully metallized indentation.

The basic concept implies corner notches on either end of the diagonal for connection. The pieces made under this contract will have electrical connection to notches 3 and 10 and a notch metallized for mechanical support at 7.

The use of stainless steel for springs has introduced another set of problems obstructing the original idea of solder coating the entire mounting structure and using the solder to bond the plate. The use of the ductile nickel was decided in part because of the ease of soldering. With the already "unsolderable" stainless inside the envelope, one of the principal impediments to a thermally matched feedthrough is eliminated. This will be reexamined to determine if a desirable surface for spot welding can be generated inside the cavity with the resulting post. If so, external surface metallizing giving the circuit flexibility desired by RCA may become feasible. This, if successful, will leave the ceramic unchanged.

The closure will have to be formed. It is practically certain that a solder seal can be readily effected between a metallized solder coated shoulder in the cavity and a metallized and solder coated edge of the square ceramic cover plate. This seal would be produced by melting the solder by induction heating in an evacuated enclosure using a directed stream or low pressure atmosphere of a chemically reducing gas (hydrogen, methane, etc.) as a fluxing agent.

The original proposal made by the Signal Corps in the RFQ specifically mentioned cold welding techniques as an alternative and potentially preferable means of seal. This had just become attractive in prospect to RCA at the end of their project. It has appealed to GE people in the Receiving Tube Department, and will be investigated as a possible means of closure.

We at Communication Products Department have less feeling of urgency about the elimination of the solder seal than some crystal people. A statement of our ideas on solder as a sealing material, on aging stability and contamination might be of interest and is therefore included here.

We are aware that a solder ball cycled a sufficient number of times between room temperature and 100°C will become embrittled and may even crack spontaneously. We are aware that this phenomenon has been responsible for the failure of uncounted numbers of silicon rectifiers operating within ratings in on-off service. Yet in our experience properly fluxed joints of 1½ inch length between pre-tinned parts display a failure rate significantly less than 0.1% after 1000 heat cycles from room to 87.5°C (our mass usage oven temperature). An accurate value for the failure rate cannot be determined at any figure greater than zero, since no units made with what we consider an adequate seal have yet been returned with seal failures regardless of the reason for return. There are many more than 1000 units in the field of this construction which have had 1000 cycles or more. We are convinced that cycling is the hazard and not temperature alone because with earlier less adequate seals our replacement rate in station equipment, which has at most 1 heat cycle per day and often is operated continuously, ran at very nearly zero while replacements in mobile equipment ran to 3% per year.

The indication is that the life of properly solder-sealed units in equipment carried on the person of the user should be indefinite. Light Military Electronics Department figures the mean time to failure for all reasons of MIL crystal units in airborne equipment without ovens at approximately 9 years.

On the other hand we find that heated operation of crystals is a severe test of the quality of cleaning of metal envelopes. Where heat cycling tends to cause the failure of solder bonds, simple heat accelerates the migration of residues of drawing lubricants, etc. from porosity in drawn metal envelopes to the surface where they can contaminate the crystal plate. When, after a period of time, a crystal in oven service suddenly starts drifting downward, it is a question to be determined whether the problem is one of seal failure or of contaminant migration in an inadequately cleaned metal envelope.

From these observations, there is ground to suspect that the severity of the heat aging test specified may have been overestimated, as these envelopes are of a fired ceramic construction and should contain no occluded organics. The thesis that solder need not be feared can thus also be defended.

## II. Mounting Structure

The present version of the spring is .002" thick and has not been heat treated. Elgin Watch Company recommends heat treatment strongly, but the recommended treatment is in an oxidizing atmosphere. Heat treatment should be withheld until after the spring is spotwelded into the holder. An oxidizing treatment under these circumstances would destroy the solderability of the nickel and cause scaling on the spring. Removal of the scale by the recommended etch would damage the ceramic.

If an annealing procedure can be applied in an inert or reducing atmosphere an improved spring may result from use from thinner stock. Ribbons of .0015" and .001" thickness are on order. In such an atmosphere a nickel flash over the stainless steel could be preserved. Under these circumstances the spring could be solder coated and the plate bonded by melting the solder coating. This whole complex of possible improvements in the spring will be explored.

Experience with Bondmaster M-640 epoxy cement filled with silver and thinned with Cellosolve Acetate for effecting the electrical and mechanical bond of the plate over a 4 year period has confirmed its quality as a bonding material. Recent experience with some rather "fussy" crystal requirements has shown that the Bondmaster, as used, is the source of a surface contamination which increases the low drive equivalent resistance and impedes "starting" of oscillator circuits. An experiment has been designed to determine if the contamination comes from the epoxy, from the solvent, or from some reaction between the solvent and the epoxy. Union Thermoelectric has tentatively assigned responsibility for the largest part of the contamination to the solvent. This experiment will determine if the epoxy is available as a bonding agent, as the scaling principle would enforce a drastically reduced level of permissible contamination on these miniature elements.

## III. Crystal Element Design and Fabrication

The principal problems seen ahead in this category are those of the required surface finish of the 70 mcs plates and the technique of frequency finishing. The resolution of the problem of solder vs cement will have some effect on the design and fabrication of plates, but only a very small effect, as the arguments for edge premetallizing are independently valid.

The simplest means of frequency finishing would be by a second evaporation overlay while oscillating. This procedure is suitable for only a limited change of frequency before a loss of activity sets in and may be suitable for only a minimal adjustment. A wider range is available by electroplating, and the fact that the spring is capable of repeated loadings and unloadings would allow a close adjustment before the bonding with a final adjustment after bonding. A final electroplate to frequency after bonding is also a possibility. Because of the close quarters, washing the plating solution off the element and out of the holder would be a slow and exacting job. To carry this out we have equipped with two miniature Soxhlett extractors which automatically rinse repetitively with fresh distilled water.

The problem of generating adequately fine surface on .0027" plates to satisfy the requirements of the units at 70 mcs is still expected to be difficult. We intend to follow up the suggestion that 5 micron or 3 micron finish may be adequate, but without great anticipation of success. The plates at 45.1 mcs will be polished, as will one side of the plates at 7.0 mcs.

The problems of generating polish at .0027" will be followed using the stretcher on 4½ and 3 inch plates and using a variety of suggested surfacing materials. Also to be tried is the set of submicron size lapping aluminas (1 micron rms, 0.3 micron rms, 0.1 micron rms) made by Linde. These are available in retail quantities from Geoscience Instruments Corp. and recommended by them for generating fine lapped surfaces with pellon lap facing. We intend to continue working with over-diameter plates to the least possible processing moment, but have tooled to work with ultimate diameter blanks all the way if that proves necessary.

We anticipate no particular problem in finding optimum orientations for the plates, as the scaling principle identifies an optimum angle with a shape, not a frequency.

The angle of the 7.0 mcs plate is the same as of its 2 mcs prototype.

## IV. Test

At the suggestion of George D. Hanchett of RCA, we propose to have encapsulation done by RCA unless exception is taken by the Signal Corps.

The 2000 hour test at 85°C has been explained as a storage test. A container will be constructed to bulk-age the units with frequency measurements being made at room temperature. The units will thus be temperature cycled only once each measurement unless this specification is changed before the test gets under way.

## EXPENDED ENGINEERING EFFORT

Communication Products Department

| | | |
|---|---|---|
| John H. Sherman, Jr. | 106 | hours |
| David R. Womack, Jr. | 74 | hours |
| George T. Winfrey | 5[illegible] | hours |

Receiving Tube Department

| | | |
|---|---|---|
| Edward J. Broderick | 6 | hours |
| Clayton G. Childs | 117 | hours |

## PROJECT DIRECTOR

**Name:** John H. Sherman, Jr.

**Birth:** August 12, 1918

**Citizenship:** U. S. A.

**Place of Birth:** Roanoke, Virginia

**Education:**

Oak Park High School, Oak Park, Ill., 1936
University of Tampa, 1940 - AB Mathematics, Chemistry
Cornell University 1940-41, Graduate Student (Physics).
Lehigh University 1946-47 MSEE (Communications)
N. C. State College 1950-51 Graduate Student

**Experience:**

1941 - 1942 Spencer Lens Co., Buffalo, N. Y. Optician
1942 - 1946 AUS Signal Corps Carrier and Repeaterman T/5
1947 - 1950 Asst. Prof. EE, N. C. State College
1951 - 1953 General Electric Co., Electronics Lab.
1953 - Present Crystal application, General Electric Co.
1957 - Present Crystal design, General Electric Co.

MECHANICAL SPECIALIST

| | |
|---|---|
| Name: | David R. Womack, Jr. |
| Birth: | June 22, 1934 |
| Citizenship: | U. S. A. |
| Place of Birth: | Charlotte Court House, Virginia |
| Education: | Randolph-Henry High 1952<br>Charlotte Court House, Va. |
| | Lynchburg Foundry Co. Apprentice Course<br>1952 - 1956 |
| | Lynchburg Center of University Ext. Div.<br>1959 - 1961 |
| Experience: | Lynchburg Foundry Co., 1952-1957 - Machinist<br>General Electric Co. 1957-1958 - "<br>" " " 1958-1959 - Tool & Die Maker<br>" " " 1959-1960 - Model Shop Technician<br>" " " 1960-Present Technical Specialist in Product Design Eng'g |

## TECHNICIAN, CRYSTAL DESIGN AND FABRICATION

**Name:** George T. Winfrey

**Birth:** February 19, 1925

**Place of Birth:** Richmond, Virginia

**Citizenship:** U. S. A.

**Education:** New London Academy, 1943
U. S. Navy 1943-46 Motor Machinist 2nd Class
(Diesel School & Advance Diesel School)
Phillips Business College, 1946-47
Nelson Bowen, Lynchburg, Va. Apprentice jeweler 1948-1949
Greensboro School of Watchmaking 1950-1951

**Experience:** American Cyanamide Co. 1951-1955 - Chemical analyst - Quality Control Lab
Piney River, Va.
Glamorgan Pipe & Foundry Co., Lynchburg, Va. 1955-1957
General Electric Co., 1957 - Present
Technician Crystal Eng'g December 1959

## PROJECT ENGINEER, CERAMIC ENVELOPE

| | |
|---|---|
| **Name:** | E. J. Broderick |
| **Birth Year:** | 1920 |
| **Citizenship:** | U. S. A. |
| **Education:** | B. S. Chem. Eng'g, Harvard University, 1943 |
| **Experience:** | AUS 1943-1946 |
| | General Electric Company |
| | 1946-1951 Analytical Chemist |
| | 1951-1957 Development Chemist (Glass & Ceramic to metal sealing) |
| | 1957-1961 Specialist, Inorganic Insulation |
| | 1961- Manager, Ceramic & Metallurgical Laboratory |

## CERAMIC ENGINEER

Name: Clayton G. Childs

Date of Birth: July 21, 1922

Place of Birth: West Clarksville, New York

Citizenship: U. S. A.

Technical Education: N. Y. S. College of Ceramics - 1953
B.S. in Ceramic Engineering

Related Work Experience: July 1953 to present - General Electric Co., Owensboro, Kentucky - development engineering work with technical ceramics and with ceramic to metal seals.

Professional & Honorary Societies:

American Ceramic Society

Keramos

AD ______ Accession No. ______
General Electric Co., Communication Products Dept., Lynchburg, Va.
MICROMODULE CRYSTAL UNITS
Semi-Annual Report No. 1
John H. Sherman, Jr.

I. Envelope and Closure
This is the substance of subcontract with the Receiving Tube Department of the General Electric Company. Prototype structures to the point of seal have proven successful.

II. Mounting Structure
Mounting structures went through six tools and two materials before a successful spring design was completed. Every crystal mounted to date has oscillated in the mount.

III. Crystal Element Design and Fabrication
Design effort is naturally focussed on the three frequencies required by the contract. The highest and lowest frequencies have posed problems of fabrication technique. The design principle employed is geometric scaling.

IV. Test
No units have yet reached the point of test against specifications in the contract.

UNCLASSIFIED

1. Micromodule Crystal Units

2. Contract DA 36-039-SC-87363

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